TMUP-HEL-0007

Answering the Sphinx's Questions on Neutrinos

Hisakazu Minakata*

Department of Physics, Tokyo Metropolitan University

1-1 Minami-Osawa, Hachioji, Tokyo 192-0397, Japan, and

Research Center for Cosmic Neutrinos, Institute for Cosmic Ray Research,

University of Tokyo, Kashiwa, Chiba 277-8582, Japan†

Abstract

In answering the difficult questions on neutrinos asked by Sphinx I argue that search for proton decay is the most important experiment in coming 5-10 years. I also emphasize the crucial importance of the neutrinoless double beta decay with sensitivity of $\langle m_{\nu e}\rangle \sim 0.01$ eV level as the unique feasible way of directly detecting neutrinos of atmospheric mass scale in laboratories. I point out that, if observed at this level, it means not only that neutrinos are Majorana particle but also that they must obey an inverted mass hierarchy.

---

*Talk presented at Workshop on Neutrino Oscillations and Their Origin, Fujiyoshida, Japan, February 11-13, 2000, to appear in Proceedings published by Universal Academy Press, Tokyo.

†Address correction requested

As one of the panellers in this session, I was asked by Yoichiro Suzuki, the head of the Priority Area Project on Neutrino Oscillations and their Origins, to answer the questions Q_1: "What would be the most important neutrino oscillation experiment in coming five years?" and the other related ones. Clearly, he was so kind to raise such a difficult question to answer. Of course, his intention was quite right, aiming at triggering interesting discussions in the session. Therefore, let me try to answer it as far as I can do.

Actually I will try to answer it by making it harder, I mean more general, not by making it more specific. (A famous mathematitian Kiyoshi Oka once claimed that one must let problem harder by making it more general to beautifully solve it.) So the question I try to answer is:

Q_2: "What would be the most important experiment in coming five years which has anything to do with neutrino masses?

Since the questions are so heavy I had to ask myself about what we know with confidence and what we do not know for sure in particle physics. After some wondering I found that the answer is simple. The standard model of particle physics [1], and that is about it.

We do know that the standard model is a great theory which explains almost everything that we know; they mostly come from the experiments done at energies of less than 1 TeV. A bit of more thought, however, reveals that it has profound consequences on physics far beyond the electroweak scale. It stems from the nature of the standard model of being a renormalizable theory. It predicts that baryon and lepton number nonconserving processes are largely suppressed. It is because the gauge invariance and the renormalizablity do not allow us to have lepton and baryon number violating interactions in the standard model [3]. These interactions are possible only as unrenormalizable, higher-dimensional operators, and hence are suppressed by powers of a large mass scale which signals the energy scale that characterizes opening of new physics. One of the simplest possible terms that violates lepton and baryon numbers is

$$\frac{1}{M^2}\bar{e}\bar{d}uu \tag{1}$$

which would mediate proton decay, $p \to \pi^0 + e^+$. This is the basic reason why the proton decay is so rare; The basic defining principle of the theory, the gauge invariance and the renormalizablity, themselves guarantee the stability of matter without recourse to any extra symmetries that can be fragile. The most stringent bound to date comes from Superkamiokande [4].

It should be stressed that the same reasoning in the standard model implies that the neutrino masses must be tiny. The lowest possible dimension 5 operator for the neutrino mass term is;

$$\frac{1}{M}\phi\phi\nu\nu \tag{2}$$

where ϕ indicates the Higgs field. We know that $\langle\phi\rangle$ is about 250 GeV. If we take $M \simeq 10^{16}$ GeV as is natural for grand unification [2], then it gives us for a neutrino mass, $m_\nu \simeq 6\times10^{-3}$ eV. Our prejudice in the hierarchy of lepton and quark masses then suggests that the largest Δm^2 is given by $m_\nu^2 \simeq 4 \times 10^{-5}$ eV, which is not so far from the Δm^2 scales implied by the atmospheric neutrino data and the MSW solar neutrino solutions. (Most probably it is in between them.)

Therefore, it appears to me that the most natural interpretation of the tiny neutrino mass which we observe by various neutrino experiments is the one *expected* by the most well-tested theory, the standard model. Its size naturally suggests the grand unification mass scale as the energy threshold for new physics. If this interpretation is correct, the next step is obvious; observation of proton decay.

Thus, guided by my conservatism in which I trust only the generic features of the standard model as a renormalizable theory based on gauge principle, I was led to an answer to the modified version of Yoichiro's question Q_2; The most important experiment in coming 5-10 years is the search for proton decay. I have no reason not to suspect that it will be observed by Superkamiokande; I do not share the pessimism which apparently possessed by the experimentalists. I hope that they are patient enough to continue to believe in this generic "prediction" of the standard model, albeit not in various GUT-model-dependent

predictions on dominant modes.

Now, since this is the Neutrino Workshop I feel obliged to address at least one neutrino experiment which I believe to be of key importance in the near future. It is the neutrinoless double beta decay experiment [5]. There are at least two impressive bold attempts to reach sensitivity of ~ 0.01 eV [6,7]. Because it is smaller than square root of the atmospheric Δm^2, we have a good chance of observing real events, not just placing the bound, if the neutrinos are Majorana particles and if the experiments are feasible. It should be emphasized that it is the unique experiment, to my knowledge, that is capable of proving of Majorana nature of neutrinos. I note that the extra Majorana phases cannot be observable in any neutrino oscillation experiments in vacuum and in matter.

I would be very happy if I can stop here. But I must point out the following fact, though it might give a little harder time for experimentalists. What I told you a moment ago was not quite correct. To clarify what I mean by this we have to distinguish the normal ($m_3 \gg m_1 \sim m_2$) and the inverted ($m_1 \sim m_2 \gg m_3$) hierarchies of neutrino masses. If neutrinos have normal mass hierarchy then a suppression factor arises so that one must go down to 0.001 eV level to probe the neutrino mass scale of $\sqrt{\Delta m^2_{atm}}$.

In my notation I assume that the 3rd mass eigenstate is either heaviest or lightest. I call the former (latter) case as the normal (inverted) mass hierarchy. I use as a lepton mixing matrix, the Maki-Nakagawa-Sakata matrix [8], the standard parametrization of the CKM matrix for quarks advertized by Partcle Data Group. Then, the observable in double beta decay experiment can be written as

$$\langle m_{\nu e} \rangle = \left| c_{12}^2 c_{13}^2 m_1 + s_{12}^2 c_{13}^2 m_2 e^{i\phi_1} + s_{13}^2 m_3 e^{i\phi_2} \right|, \tag{3}$$

where ϕ_1 and ϕ_2 are undetermined phases, essentially the two extra Majorana phases. Since $\Delta m^2_{atm} = \Delta m^2_{23} \simeq \Delta m^2_{13} \gg \Delta m^2_{12} = \Delta m^2_{solar}$, $\langle m_{\nu e} \rangle$ is dominated by the 3rd (1st and 2nd) term in (3) for the normal (inverted) mass hierarchy if I rely on the view represented in (2) with $M = M_{GUT}$. An opposite extreme is known as the almost degenerate neutrinos (ADN), $m_j^2 \gg \Delta m^2_{ij}$, and I refer an early analysis [9] of the ADN scenario on how it can be

constrained by the solar neutrino observation.

Now it is simple to observe that in the normal mass hierarchy $\langle m_{\nu e}\rangle$ is given by

$$\langle m_{\nu e}\rangle = s_{13}^2 m_3 \simeq s_{13}^2 \sqrt{\Delta m_{atm}^2}. \tag{4}$$

The constraint by the CHOOZ experiment [10], $\sin^2 2\theta_{13} \lesssim 0.1$ and $\Delta m_{atm}^2 = (2-5) \times 10^{-3}\text{eV}^2$ gives $\langle m_{\nu e}\rangle \lesssim (1.1 - 1.8) \times 10^{-3}$ eV. On the other hand, if the inverted mass hierarchy is the case

$$\langle m_{\nu e}\rangle \simeq \left| c_{12}^2 m_1 + s_{12}^2 m_2 e^{i\phi_1} \right|, \tag{5}$$

which, barring the possibility of accidental cancellation, can be of the order of $\sqrt{\Delta m_{atm}^2}$, as announced in the abstract.

I don't know if I survived the Sphinx's questions. But what I told you in my talk is in what I believe. So let us wait and see.

In completing this manuscript I noticed that the similar issues on double beta decay have been addressed in [11].

I thank Yoichiro Suzuki for asking such difficult questions and keep pressing us to answer. This work is supported partly by the Grant-in-Aid for Scientific Research in Priority Areas No. 12047222 Ministry of Education, Science, Sports and Culture.

REFERENCES

[1] S. Weinberg, Phys. Rev. Lett. **19** (1967) 1264;

A. Salam, in *Elementary Partcle Theory*, ed. N. Svantholm (Almquist and Wiksell, Stockholm, 1968); S. L. Glashow, Nucl. Phys. **22** (1961) 579.

[2] H. Georgi and S. L. Glashow, Phys. Rev. Lett. **32** (1974) 438;

J. C. Pati and A. Salam, Phys. Rev. Lett. **31** (1973) 661.

[3] S. Weinberg, Phys. Rev. Lett. **43** (1979) 1566;

F. Wilczek and A. Zee, Phys. Rev. Lett. **43** (1979) 1571.

[4] M. Shiozawa, Doctor Thesis, ICRR-Report-458-2000-2.

[5] M. Doi, T. Kotani and E. Takasugi, Prog. Theor. Phys. Suppl. **83** (1985) 1.

[6] GENIUS Collaboration (L. Baudis et al.), hep-ph/9910205.

[7] H. Ejiri et al., nucl-ex/9911008.

[8] Z. Maki, M. Nakagawa and S. Sakata, Prog. Theor. Phys. **28** (1962) 247.

[9] H. Minakata and O. Yasuda, Phys. Rev. **D56** (1997) 1692.

[10] CHOOZ Collaboration, M. Apollonio et al., Phys. Lett. B**466** (1999) 415.

[11] H. V. Klapdor-Kleingrothaus, H. Pas and A. Yu. Smirnov, hep-ph/0003219.